A SKETCH OF THE HISTORY OF REFLEX ACTION.

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II.

BELL'S LAW.

The modern history of the nervous system may be said to begin with Charles Bell's demonstration of the law which bears his name; *viz.*, that the *posterior roots of the spinal nerves are sensory, the anterior motor.* Bell justly complained that the anatomists of his day had become disheartened by the seemingly irregular and lawless complexity of neural fibres. To those who know least of the actual anatomy of the parts, Bell says, the prevailing theories seem most ample and satisfactory; while those who study deepest only discover error and confusion. No wonder they had recourse to the authority of the ancients. Haller declared, as Galen had done, that the same nerve which conducted sensation also carried motion. But on any of the theories then extant, how the same little nerve could carry a motor impulse one way and a sensory impulse the opposite way at the same time was a confusing puzzle. Bichat (1771—1802) had distinguished the sympathetic, (or as he mistakenly called it, the ganglion system,) which presided over the functions of organic life, mediated sympathies between various parts of the body, was comparatively insensitive, and not directly under the control of the will, from the cerebro-spinal system. Curiously enough in 1809 Alexander Walker, a Scotch anatomist, claimed to have proved the converse of Bell's Law; *viz.*, that the posterior roots were motor and the anterior sensory.

Bell was accused of dissecting brains to find the seat of the soul; and this he denies in his first work upon the subject,[1]

[1] Charles Bell: Idea of a new anatomy of the brain. Submitted for the observation of his friends. Lond., 1811. The copy to which I had access is a transcription "made by H. U. D., 1813," in the possession of Dr. H. H. Donaldson.

saying that his only wish is to investigate the structure of the brain as we examine the structure of the eye or ear. Nowhere in this paper is the Law formally stated. But from it is seen that Bell is deeply imbued with the ideas which underlie, not only his Law, but the physiology of the nervous system as it is now understood. "The nerves of motion, the nerves of sensation and the vital nerves," he says, "are distinct throughout their whole course" (op. cit. p. 7). "The nerves which we trace in the body are not single nerves possessing various powers, but bundles of different nerves whose filaments are united for convenience in distribution; but which are distinct in office as they are in origin from the brain" (op. cit. p. 6). As is well known, Bell outlines the theory of specific energy of nerves. "An impression," he says (op. cit. p. 11), "made on two different nerves of sense, though with the same instrument will produce two distinct sensations, and the ideas resulting will have relation to the organs affected. Piercing the retina with a cataract needle gives a flash of light, and a blow on the head makes the ears ring and the eye flashes light, but no sound or light are present." The effect depends upon the part of the brain excited. Penetrated with these conceptions Bell sought to answer intelligently the following questions: 1, Do the nerves of the trunk and limbs derive the ability to perform their functions from a combination of peculiar forces received from the different parts of the cord indicated by their double roots? 2, Is this the reason why their course is simple or isolated as compared with the cerebral nerves? 3, Which nerves of the head and face correspond in structure with those of the trunk? Bell was acquainted with the sensory and motor effect of irritating the anterior and posterior columns respectively. On this point he says (op. cit. p. 26), "I found that injury done to the anterior portion of the spinal marrow convulsed the animal more certainly than injury done to the posterior portion." Thence he was lead to observe a corresponding difference of function for the roots. He continues (op. cit. p. 27), "On laying bare the roots of the spinal nerves, I found that I could cut across the *posterior fasciculus* of nerves, which takes its origin from the

posterior portion of the spinal marrow, without convulsing the muscles of the back; but that on touching the *anterior fasciculus* with the point of the knife the muscles of the back were immediately convulsed."

In a later paper[1] Bell lays down the principle that complexity of nervous supply to an organ indicates a corresponding complexity of function. An organ with but a single nerve has but one function to perform; while the tongue, for which he observed five distinct sources of nervous supply, was employed in as many ways. For a voluntary muscle he asserted the existence of a double nervous supply, a *nervous circle*, one arc of which transmitted the excitement of the brain to the muscle, the other carried the sensation of the muscle to the brain. The proof of this he sought in the fifth nerve where besides direct fibres to the muscle there are also fibres which enter the muscle after passing the ganglion of Gasseri. The latter must be sensory nerves according to a fundamental principle which he had laid down, that no motor nerve was ever interrupted between its origin and its peripheral end by ganglia. All nerves, he admits, may be divided into these two classes, sensory and motor, but in view of the division in function and for convenience sake he prefers to make a separate class for the "respiratory nerves," *i. e.*, the nerves which co-ordinate the muscles for respiration, expression of emotion, etc. It was the investigation of this class which led Bell to his great work upon the nerves of the face and chest, and this in turn brought to light many facts in support of his Law. As has been shown, he performed experiments upon living animals to demonstrate his Law to his own satisfaction, but his aversion to vivisection and his predilection for anatomical methods no doubt delayed a full comprehension of the scope of his discovery; but an extended collection of faithful observations confirmed it beyond all doubt, and he boldly asserted its validity for each of the thirty-one pairs of nerves in man, as well as for all forms of lower vertebrates.[2]

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[1] Charles Bell: On the Nerves; giving an account of some experiments on their structure and function which lead to a new arrangement of the system. Phil. Trans., 1821. pp. 398—424.

[2] See, Charles Bell: The Nervous System of the Human Body; embracing the papers delivered to the Royal Society on the Subject of the Nerves. R. S. London, 1830.

From studying the effects of cutting the facial and then the maxillary nerve in asses and monkeys Magendie (1783—1855) was led to sever anterior and posterior spinal roots, and declared that he had at last established by direct experiments the difference between sensory, or posterior, and anterior, or motor, fibres. In examining the body of a patient who had lost all power in his arms while sensation in them remained intact, he found the anterior roots considerably decayed. This law he found to be valid along the entire length of the cord, from which Legallois had already proved the motor and sensory powers of all organs without exception to be derived, one part of its surface being exquisitely sensitive and another part motor. It might thus be expected, Magendie declared, that as we pass from the surface to the centre of the cord we should reach a "secret sanctuary" where sensation perhaps passes into motion. This, however, is not the case, for, as he says, touching the centre of the cord causes neither sensation nor motion.[1]

This paper of Magendie[2] was published as an entirely independent and original observation and the claim of priority in the discovery of the law in question was at once made for him. While it seems on the whole probable that his method of demonstration was more conclusive than that of Bell, there is little doubt that the latter deserves to be called the discoverer. From other earlier papers of Bell it appears that, although not clearly recognizing the principles he finally established, he was penetrated with the idea that the difference of neural functions was grounded in anatomical differences;[3] and there is little doubt that Bell's results, which his assistant went to Paris in 1821 to demonstrate on the facial nerve, had been seen by Magendie. To him, however, belongs

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[1] Magendie: Sur quelques découvertes récentes relatives aux fonctions du systeme nerveux. Annales de chimie et de physique. Vol. 23, p. 429. Paris, 1823.

[2] Magendie: Leçons sur la Physiologie. Paris, 1839.

[3] For a good digest of Bell's earlier opinions, see *Karl Bell's Darstellung der Nerven; frei bearbeitet von Dr. H. Robbi mit einer Vorrede von I. C. Rosenmüller.* Leipzig, 1820.

the merit of introducing what was first established as an anatomical and pathological law into the fruitful field of physiology.[1]

Bell's discovery at once excited the liveliest discussion on the continent. Many doubted the validity or at least the universality of the Law. Of those who were convinced of its truth, some raised the further inquiry as to how the sensory and motor roots were distributed peripherally. The greater number of investigators, however, were led to study the functions of the various columns of the spinal cord to ascertain how far the distinction of sensory and motor could be traced in it. Bellingeri distinguished three pairs of columns in the spinal cord. The anterior pair were connected with the cerebrum, the posterior pair with the cerebellum. The lateral, restiform, and pre-eminently ganglionated columns mediated organic and instinctive functions. The anterior roots were composed of fibres from each of these columns. So too were the posterior roots. Those fibres of the anterior roots which sprung from the anterior columns mediated voluntary motions, and the fibres of the posterior columns which sprung from the posterior horns of the grey substance were exclusively sensory. All fibres, of which root soever, that took their rise from the posterior cerebellum columns innervated extension muscles, and those from the anterior columns innervated the flexors. For this latter conception he found fanciful ground in the phenomena of *episthotonus* and *emprosthotonus*.

Schoeps, in 1827, concluded that motility required more nerve-force than sensibility, and that the former was more impaired by section of the anterior root than by section of the

[1] Charles Bell. Nervous System of the Human Body. A note in explanation of this point states that "in Dec. of 1821, Mr. Shaw wrote a paper on the facial nerves in *Brandis' Journal of Science*. In this he stated, that at the request of M. Magendie he had repeated Mr. Bell's experiments on the face of a horse at Charenton, near Paris, and had at the same time presented to M. Magendie a copy of the Manual above mentioned (Manual of Anatomy; Explaining Mr. Bell's System; by John Shaw). * * * * It was after all this (in July, 1822) that M. Magendie published his paper on the nerves of the spine. On its arrival in this country, M. Magendie was informed that these experiments had been performed in Great Windmill Street, which he acknowledged in his next Journal, with the addition, that, although Mr. Bell had preceded him, his own proofs were more complete."

posterior, because the latter was feebler, smaller, and not generally able alone to move a limb. He grants that there is more mobility in the anterior columns and roots, and more sensibility in the posterior, but concludes from his experiments adversely to Bell's assertion of a complete division of function. Becker, in 1830, vindicated an absolute division of function, upon experimental and pathological grounds. Langenbeck, however, the following year, thought Bell's Law as speculative as Gall's localization of cerebral functions. As the activity of the brain may involve the functions of the entire mass, so the cord may be motor or sensory throughout. The fact that the anterior and posterior columns are so intimately connected, and the two halves of the cord are interlinked by so many commissural fibres, made a division of functions seem improbable. The fibres of both roots, moreover, are so intricately interwoven, after leaving the cord, in the plexus that the integrity of each of the two systems seems impossible. Experimental objections were urged only against Bell's assertion that the facial is exclusively a motor, and the trigeminus a sensory nerve.

Much light was thrown upon the matter in the first volume of Müller's *Physiologie*, in 1834. He may be said to have established Bell's Law in Germany. One reason why previous observers had found such difficulty and reached such conflicting results in their investigations was that most of them had used warm blooded animals, the nerves of which, especially of the posterior roots, speedily lose their power and die in consequence of the necessary operations. Another reason was that many of them had not clearly distinguished between reflex and direct stimulation, nor between the results of stimulating the peripheral or the central end of the sensory root. Müller used frogs, the large accessible and persistently vital nerves of which make them especially fitted for such studies, and he compared the effects of stimulating the severed peripheral ends of each root. Any clear distinction between anterior and posterior columns, either anatomically or functionally, Müller discountenanced; still more so the idea that the outer or white substance mediated motion and the grey central substance sensation. He was moreover inclined to regard the

spinal cord as the common collective bundle of all the trunk nerves, rather than as a part of the central organ. Bell's theory, though ingenious, he thought had not been hitherto satisfactorily proved. His own method established it with a simplicity and certainty not inferior to that of the best physical *experimentum crucis*. These results were confirmed by applying galvanic irritations to both roots. Panizza and Van Deen confirmed Bell's Law by new and manifold experiments.[1] The last sought to determine which parts were innervated by the single nerves, and concluded that the seventh pair of the frog mediated the movement of flexing the thigh against the belly, the eighth, all the movements of the hip and knee, and the ninth pair of nerves the movement of the foot and toes. He inferred that in the plexus sensory and motor nerves cross and intertwine without losing or interchanging their functions. The use of the plexus according to Van Deen was to be found in the fact that different movements which traverse it at the same time are easier and more harmonious. The position, connection, and form of the muscles was determined by the position and form of the plexus. The peripheral ending of sensory nerves is in the skin, that of the motor nerves in the muscles. The two can be compared with the veins and arteries which often run side by side, but the motions mediated by each are in opposite directions and they communicate directly with each other. The nerves like the muscles of the two halves of the body are symmetrical and unconnected save in the higher nerve centres. Here the ends of sensory and motor nerves lie near together in order that the latter may observe the behests of the former. Longet, whose investigations were published in 1841, thought galvanism peculiarly adapted to demonstrate Bell's Law on higher mammals. He severed the anterior roots of one leg leaving the posterior roots intact, and even after administering small doses of strychnine observed no motion upon that side while the other was violently convulsed. The galvanic current was applied directly to the strands of the cord with

[1] For a brief sketch of the work of these and several other investigators, see J. W. Arnold: Ueber die Verrichtung der Wurzeln der Rückenmarks Nerven. Heidelberg, 1844.

many interesting results which were, however, largely vitiated from the same cause that led him to suspect the results of his predecessors, *viz.*, that the currents used were too strong. An anonymous writer, who accepted the fact that section of anterior and posterior roots destroyed motion and sensation respectively, still protested against the presupposition of Bell's Law that motion and sensation were two distinct functions, because in morbid or abnormal conditions they seemed to be more or less isolated.[1] "There are points in the nervous system," he says, "where sensation and motion pass over into each other; it is one and the same soul that feels and moves, while if Bell were right two souls, one sensory and another motor, would be conceivable. Nothing can be more casual and external than the merely spacial distinctions between anterior and posterior, and yet the re-iteration of this distinction is all Bell's school have accomplished, and this is made essential in the nature of the soul. Instead of interpenetration of functions necessary to true psychic unity, Bell offers a mechanical juxtaposition and agglomeration, which encourages speculative anatomy and is no less unscientific and disintegrating than phrenology or a supposable theory that muscles have flexor and extensor fibres." He concludes that our soul would be much poorer than it is in feeling and action, if motor nerves did not conduct centripetally and inform us of the condition of our muscles and if sensory nerves did not lead outwardly.

III.

The Physical Versus the Psychic Theory of Reflex Action.

The labors of Bell, Magendie and Johannes Müller had made known in a practical way the anatomical elements concerned in reflex action; *viz.*, a centripetal and a centrifugal nerve with their portion of the spinal cord. Anatomy out of the way, the next question was one of physiology, namely, do these parts operate upon mechanical principles or not? That the mere transmission of an impulse along a nerve is purely

[1] Roser und Wunderlich's Archiv. Jahrg. I. S. 295.

mechanical can hardly be doubted, but what of the central process by which a sensory is changed to a motor impulse, and so directed as to cause definite movements of the muscles?

The first to elaborate a mechanical theory of reflex action was Marshall Hall. Besides the cerebral system, which mediated the functions of sensation and volition, and the ganglionic, which presided over the functions of nutrition, he assumed a third, *viz.*, the true spinal system. This last he describes as follows: "The spinal cord of vertebrates consists of two parts very closely connected with each other, not easily separable anatomically, and perhaps only to be distinguished by physiological and pathological methods.[1] The first part is a bundle of nerves which subserve the purpose of sensation and volition. The central organ for these fibres is the brain, from which they proceed and to which they return. The second part, which may be designated as the true spinal cord is distinguished by the excito-motor nerves. Generally, though perhaps not invariably, it is connected with the former system." The answer to the question how far excitory nerves can be separated or distinguished from sensory and motor nerves from voluntary, he assumed must be sought in invertebrates, which lead an excito-motor life with little sensation or volition, because in them the nerves need not be clustered into bundles in passing out from the spinal cavity between two vertebræ. He regarded the opticus and acusticus as purely sensory, without excitory functions. The tonicity of muscles he considered as the result of excito-motor force, mediated by motor nerves which are enclosed in the same sheath as the volitional nerves, and observed that this power is active in sleep in all muscles except the *levator palpebrae* and perhaps the *recti*. Hence he concludes that the nerves which innervate these are purely volitional without motor power. This opinion, however, is not put forth with great confidence and still less is he disposed to insist upon the existence of purely excitory nerves. He regarded, however, the pneumogastric as the least sensory

[1] See his writings *passim*, but especially his Memoirs on the Nervous System. London 1837. Translated into German by G. Kürschner, Marburg, 1840; p. 50 of the Ger. edit.

and the most excitory of all nerves among the vertebrates. But, although the anatomical distinction between these systems may be questioned, the action of narcotics, the movements of decapitated animals, cases of paralysis and all convulsive diseases, on which he made many observations, warrant the inference, not only of an independent system, but even of two roots in every sensory-excitory and in every volitional-motor fibre, one ending in the cord, the other in the brain. The excito-motor system never sleeps, but constantly watches day and night, with great, though not absolute independence from the brain, over all the openings of the body, eyes, nostrils, mouth, larynx, and all the sexual and excretory passages. There is *nothing whatever that can be called psychic connected with any of its activities*, and Marshall Hall assured his readers with much complacency that all the complexly co-ordinate and seemingly purposive movements made by the brainless animals he so long and diligently studied, snakes, tritons, frogs, cats, dogs, rabbits and leeches, etc., are unattended by sensation or by any other *rudimentary form of consciousness even in the least degree*. If the head of an eel be first removed, the trunk may be skinned without the "abominable cruelty" of the ordinary practice, for then all its writhings are purely mechanical. Formerly, he reminds us, irritability or the *vis in sita* of muscles was thought to be sensory-volitional, and he claims for himself the merit of distinguishing it from excito-motor action. The vital functions die in the following order: first the sensory-volitional, located in the brain; then the respiratory, centered in the *medulla oblongata;* then the excito-motor or reflex; and lastly muscular irritability, of which *rigor mortis* is the "last act." Lethargy may be so deep as to affect even the lowest of these functions. The embryo in its development reverses this order, and the fœtus before birth is only irritable and reflex. Hall was well acquainted with the works of his contemporaries in France and Germany, and identified excito-motor power with Haller's "*vis nervosa*," Müller's "*motor-power*," and Flourens "*excitability*." He accepted the law of isolated conductivity of nerve fibres, but believed spinal motor-power could work in both directions and made observation that reflex contrac-

tions differed from direct in occurring more "gradually" and in being less local.

G. Kürschner, the translator of Hall's treatise into German, wrote a long and suggestive appendix, full of independent and confirmatory observations. His experiments led him to the conclusion that in the spinal cord sensory and motor nerves are distinct from each other, the former composing the posterior, the latter the anterior column. Although separated, both species of fibres are most closely connected with each other, probably through the action of the grey substance. Each group of sensory corresponds to a distinct group of motor-fibres in such a way that in different parts of the cord, one and the same sensory group is connected with several motor groups, and hence it is that every spot of the skin, *e. g.*, corresponds to certain motions of the muscles.[1] Thus he infers that perhaps all possible combinations of muscular motions may be preformed in the structure of the cord and the *medulla oblongata*, and that the sensory nerves of the external surface of the body are connected with combinations which cause single motions and change of place, while those connected with the inner mucous surface occasion so called organic reactions. When brain and cord were destroyed gradually downward, Kürschner believed that the manifoldness and complexity of the body or of any single limb were gradually lost before the sum of its mobility was sensibly affected. Müller had assumed that the striking difference observed between the action of the muscles of the "animal" system and those of the "organic," as they were then called, was due to the difference in the mode of innervations, while Kürschner argued that it was due to differences of texture and structure in the two classes of muscles, and showed that the same irritation to heart, intestines and voluntary muscles gave in each case the characteristic sort of contraction produced by normal innervation. Kürschner believed that the activity of the ganglia incited motion "as water drives a mill," while the cord, besides exciting action, at the same time prescribed its forms. Single movements, as flexions, extensions, etc., he believed

[1] Kürschner; Uebersetzung von M. Hall, appendix, p. 216.

were reflexly combined in the cord; the "single motions, of which every part of the body is capable," are co-ordinated in the *medulla oblongata*, while the movements of the limbs are combined into co-ordinated movement within the cerebellum. Kürschner, however, agrees with Müller that Hall's hypothesis of a complete and special excito-motor system is untenable, and thinks we might as well accept Stilling's argument that there are special nerves for the sensations of heat and cold.

The theory of Marshall Hall at once excited interest, especially in Germany, where it has led to many fruitful investigations, and provoked many controversies. Rudolph Wagner declared it a mere hypothesis, while Henle asserted that all grey substance acts reflexly. Dupré rejected the hypothesis of a special excito-motor system and assumed that reflex functions are mediated by peculiar communicating fibres in the cord. Budd distinguished two species of reflexes, one centered in the brain and attended by sensation, and another in the cord, unattended by sensation. Many observations were made to determine the truth of Hall's statement that brainless animals never moved spontaneously; while the peculiar psychological turn which the discussion often took shows how far metaphysical conceptions had pervaded even the medical profession.

While the French society for the study of condemned criminals achieved very little for science, a single careful experiment by Bischoff and two of his colleagues, though attended with only negative results, deserves mention. The head and body of a freshly decapitated murderer were placed by the authorities at his disposal. Objects were thrust toward the eyes, the word "pardon" was shouted into the ear, a strong tincture of assafœtida was held before the nose, but all absolutely without result. Slight and repeated movements of the jaw and tongue followed the application of collodion to the latter. Spirits of wine produced the same effect. These movements, however, were thought to be due neither to sensation nor reflex action, but to irritation of the severed ends of nerve-fibres in the spinal cord. All these observations were made within less than one minute from the fall of the execu-

tioner's sword. The features were calm and natural as in life, only the eye-lids were partially closed and the pupil slightly dilated. There was also reason to believe that he was perfectly conscious at the moment of the fatal blow. The eye-lids, lashes, conjunctiva, mucus membrane of the nose, mouth, and throat were next touched. A needle was thrust into the central end of the severed cord, which was also touched with a caustic substance, all within the next one or two minutes, but no further movements whatever were observed, indicating that the nerves had ceased to be irritable and that consciousness was extinct. The severed carotid arteries of the body were tied up as soon as possible, and about half an hour after the blow, it was irritated in various ways and places, but, although direct application of electricity caused contraction in various muscles, there were no signs of reflex functions.[1]

Volkmann who had previously expressed the belief that the cord had sensory functions,[2] was led later to change this opinion, and to write, after recapitulating Hall's argument, as follows : "Strictly considered, however, such experiments prove only that that part of the body furnished with the brain, does not feel the irritation of that part which has been severed from its connection with the brain. But whether the isolated cord does not have sensations of its own, obscure though they be, is not manifest. In lower animals the sensitive principle is unquestionably divisable ; whether anything analogous can be assumed for higher animals, can scarcely be decided. All through the history of psychic development, sensation necessarily precedes volition, so that a sensitive organism without voluntary motion is easily conceivable. Yet an observer of another organism can infer the existence of sensation only from the play of voluntary motion. Hence although the latter ceases with decapitation, sensation itself is not necessarily lost ; its demonstrability becomes impossible. Impossible as it is to prove that decapitated vertebrates are insensible, still we are unable to assume for them the power of sensation. At any rate we have no occasion to conceive consciousness as divisible in the higher animals, and, as

[1] Bischoff, Müller's Archiv, 1838, p. 489 ff.
[2] Müller's Archiv, 1838, p. 15 ff.

above explained, we can assume the power of sensation to exist only where the perceptions of nerves of sense become the possession of consciousness."[1] Volkmann does not regard the brain of the lower animals as exclusively the organ of the soul. Of animals which have the cord and *medulla oblongata* intact, Volkmann says, their movements cannot be called reflex. "Rather the entire behaviour of animals so mutilated is so characteristically psychic that we have no tenable ground to deny the co-operation of the psychic principle. It only seems doubtful to me what height of development the soul can reach with so small an amount of brain matter. I consider it probable that the condition of the soul in such cases is dream-like. Sensations are certainly perceived, only they must be more obtuse and very limited after the removal of the specific organ of sensation. Obscure conceptions (*Vorstellungen*) seem also to be present with which the first efforts of the animal are connected and from which again movements proceed. Such movements do not rise indeed to the full freedom of volition; and just as little do they sink to the mechanism of reflexes."[2]

Later Volkmann opposes Marshall Hall's assumption of a spinal excito-motor system; for upon this theory not only must the number of specific fibres be increased to an impossible extent, but the fact cannot be explained that stimulation of a single sensory fibre may excite a very few motor fibres or a vast number, or in fact, all the motor nerves in the body.[3]

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[1] Wagner's Handwörterbuch, Bd. I, 1842, p. 576.

[2] A. W. Volkmann, article, Gehirn, Wagner's Handwörterbuch der Physiologie, Vol. I, 1842, p. 582. The precise status of the debate is well shown by the experiment to which Volkmann here appeals. A frog, from which he had just removed forebrain, cerebellum and optic lobes, was placed in a shallow dish of water and lay motionless and apparently dead for half an hour. At the end of this time, it raised its head as if for breath, and after a while began of its own accord to swim, making the motions at first clumsily and afterwards with more precision. The movements here could in no sense be called reflex (Volkmann supposed), because they do not begin as stimuli at the skin which are carried to the spinal cord and thence reflected into the muscles; the action was only outward; it began spontaneously in the cord. But the entire absence of external stimuli is difficult to prove, and in this case venosity of the blood and contact with the water are wholly neglected.

[3] Volkmann, Nerven Physiologie, in Wagner's Handwörterbuch, Vol. II, p. 546-7, 1844.

Hall had made some explanation of how the sensory irritation passed through the cord in being reflected outward into motor nerves; but he does not himself attach much weight to this point.[1] Grainger thought he found in each spinal root a portion which turned upward toward the brain and another portion which buried itself immediately in the cord. Spies, carrying the fallacy a step further, assumed a direct connection of excito-motor fibres with each other in the cord. To all this Volkmann objected on the ground of too great complexity, and argues at considerable length for the hypothesis of a transmission of irritation from one nerve fibre to another.[2] This may occur for all nerves, in the cord, in plexi, in the ganglia, and in the brain; while the law of isolated conductivity holds for the peripheral nerves. Not only is reflex action thus explained, but all sympathetic movements and sensations and even *delirium traumaticum*, where a painful wound causes delirium without fever. Even indistinct vision and a defective musical ear are perhaps due to the transition of the irritation from the nerve previously affected to the others which lie near it; and we learn to distinguish fine motions and tones probably by learning to isolate the action of nerves. In fatigues which are painful the state of the motor nerves springs over to the sensory, and in this way the normal association of movement may sometimes be explained. The removal of the brain or the inhibition of its action in sleep increases the facility of such transitions in the cord; while attention sometimes causes more perfectly isolated conductivity of the fibers. Nerve activities which are naturally isolated may become combined by habit and training and may be re-isolated by disuse. The excitation of many fibres may in this way sometimes be concentrated upon one point.

The claim for priority in formulating the excito-motor

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[1] Marshall Hall, New Memoirs on the Nervous System, pp. 37-38, London 1843. After calling it the "questio maxime vexata" among writers upon reflex action, he adds with reference to separate volitional-sensory and excito-motor fibres: "nothing of the kind has ever been proved; the two distinct orders of fibres have not been divided or irritated distinctly."

[2] Wagner, op. cit. p. 528, et seq.

hypothesis was made for Johannes Müller. But he himself repudiates this and shows that his view is quite distinct from that of Marshall Hall, and in many respects it must be admitted to be the more consequent of the two.[1]

Müller maintained that it is by no means necessary that sensation should always attend reflex action. "According to my opinion," he says, "the stimulation of a sensory spinal nerve causes a centripetal action of the nerve principle, which reaches the cord. If this can pass on to the *sensorium commune*, it becomes a conscious sensation. But if, on account of section of the spinal cord, it cannot reach the sensorium, it expends its entire force as a centripetal action upon the cord. In both cases reflex movements may result, in the first instance attended by conscious sensation, in the second, not."

As many German physiologists since have done, Müller rejected Hall's hypothesis of specific excito-motor fibres.

Pflüger began his able, but somewhat violently polemic, work by declaring in his preface that consciousness is motion, and has no being. As such it is a part of the great life of the world. Consciousness exists only where central nerve substance is found. It is extended in space and by whatever name it is called, whether sensorium or soul, it is divisible in all animals with its material substratum. After a short discussion of other views, recognizing especially Whytt, Prochaska and Legallois as his predecessors, he proceeds to develop as follows his well known theory of a "spinal cord soul."

Reflex action Pflüger defines to be the operation of that neuro-physic mechanism, by means of which the peripheral sensory fibre, by whatever cause excited, alters through the mediation of the spinal cord, the ordinary state of excitation of definite motor nerves.[2]

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[1] Müller, Handbuch, Vol. I, p. 622. See also Du Bois-Reymond. Gedächtniss Rede auf Johannes Müller; in Abhandl. d. k. Akad. d. Wissensch., zu Berlin, 1859.

[2] Pflüger, Die sensorischen Functionen des Rückenmarks. Berlin, 1853, p. 62. This work also contains valuable references to the earlier literature relating to this question.

The change thus caused in motor nerves may be of such a nature as to effect the shortening of the muscles, giving us a reflex contraction or reflex cramp; or it may cause the muscle to relax, resulting in the phenomenon of reflex inhibition or paralysis. These processes, he remarks, must be widely distinguished from those of sympathetic or irradiated sensations. These latter have been explained by some as occurring in the spinal ganglia, which act as imperfect conductors and arrest weak excitations, while stronger impulses spring over and stimulate neighboring fibres and are reflected outward according to the law of isolated conduction. This, however, is not sufficient, for sympathetic sensations arise in nerves which pass no ganglia, *e. g.* nasal tingling from looking at the sun, and in those which enter the cord remote from each other.

Reflex action, Pflüger believed, could be best studied in men and so, after searching through a great number of cases of reflex neurosis from German, French and English pathological literature, he was led to his well known laws of reflex action, which he states as follows:

I. LAW OF UNILATERAL REFLEXES.—*If peripheral stimulation causes contraction in only one half of the body, the contraction always occurs on the same side as the stimulus, and in general those muscles contract whose nerves arise from that segment of the cord, to which the irritated sensory nerve belongs.*

II. LAW OF REFLEX SYMMETRY.—*If the effects of stimulating a sensory nerve upon one side extend to the other side, only such motor fibres are called into activity as correspond with those which are already excited on the side of the stimulation.*

III. LAW OF UNEQUAL CONTRACTION ON THE TWO SIDES.—*If the contraction is unequal on the two sides, the stronger reflex is always on the side of the stimulation.*

IV. LAW OF REFLEX IRRADIATION.—*1. When stimulation of a cerebral nerve causes reflex contractions, the motor nerve concerned is invariably either in the same level as the sensory nerve, or it is further downward toward the medulla oblongata. 2. When stimulation of a spinal nerve causes*

reflex contractions beyond its own segment, irradiation always takes place toward the medulla oblongata.

In the former case the nerve stimulated may be a nerve of special sense; thus for example, an irritation of the optic nerve is reflected outward along the oculo-motor.

V. THE LAW OF THE THREE LOCATIONS OF REFLEX CONTRACTIONS.—*Upon stimulation of a sensory nerve, reflexes can occur in only three parts of the body.* These are: *a.* at the level of the stimulated nerve; *b.* in parts innervated from the *medulla oblongata; c.* in the whole body.

After citing pathological cases illustrating these laws in full, Pflüger describes his own experiments. By the first law the trunks of eels, fish or salamanders (which move in but two directions), if separated from the brain and irritated on one side, *e. g.* by a candle flame, should be drawn directly towards the side irritated and thus fully into the fire. He found, however, the opposite always the case. Even a small end of the tail was reflected away from the fire. But if the animal had been put under the influence of strychnine, its tail followed the law and reacted into the flame. This difference he infers to be due to the presence of a rudimentary consciousness in the former case.[1] Exactly similar results were obtained from young kittens in which the spinal cord had been divided in the dorsal region. The whole subject, however, may best be studied in the frog. When the skin of a decapitated frog is pinched in the middle of the belly, both feet strive to push the hand or tweezers away, while if the same place be touched with acid the reaction consists in rubbing the irritated spot. If one side be irritated and the leg of the irritated side be severed, the other leg is slowly brought around to remove the irritating object.

Finally Pflüger urges[2] that if the brain were the only organ of sensation, all sensory fibres must go to it and that after section of the cord an irritation of the upper surface of the section would cause sensation which by the law of eccentric projection would seem to be located in all parts of the

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[1] Op. cit. p. 112 ff.
[2] Op. cit. p. 130 ff.

body below the section, while an irritation of its lower surface would cause contraction of all the voluntary muscles below the section. The fact is, however, that if the upper part of the cord be injured the sensation of pain is located not in the legs, but in a band around the body. While if the cord be gradually destroyed from above downward, instead of motions of all the parts at once, the muscles of the arms, breast, belly, thigh, etc., are successively stimulated. These facts go to prove that both motor and sensory nerves end in their respective levels of the spinal cord and not in the brain, which so many would make the sole organ of sensation and volition. The brain Pflüger regards as a reservoir of motor forces. By its instrumentality sensations can be compared, and expressed verbally and otherwise, while the cord can respond only by moving. Even motion, however, is probably not a certain index of the presence of the dull, undifferentiated sensations, which are assumed in the cord and which, it would seem, must rise above a certain threshold, before motion can follow. In the reflexes during sleep, Pflüger also observed that if the nostrils of a sleeping child be tickled and the hand on that side gently held, the other hand is brought to the irritated point, and he expressed the belief that none of the functions of the sensorium, extended through the cerebro-spinal system, are suspended during sleep, but that sensorial activity is reduced uniformly throughout.

The bitterness and arrogance of Pflüger's style is in strange contrast to the calm, impersonal tone of Lotze's argument and reply. Lotze, it should be premised, had previously urged that reflexes, and perhaps the lower forms of instinct, are purely mechanical.[1] Nature, he says, must lead the soul by the hand a little way into the strange land of space and matter. For each stimulus that breaks upon it from the outer world, a mechanism must be furnished ready made to its use which shall respond with an appropriate movement, or the impulse to it (p. 194.) By this means, nature shows the immaterial, unspatial soul, by purely physical connections,

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[1] Lotze. Instinct. Wagner's Handwörterbuch der Physiol., Vol. II, p. 191.

what purposive movements to make. After the soul learns these elementary motions, it weaves them in ever richer and more complicated patterns; but, these elements themselves, it can neither invent nor construct. They are like the letters of the alphabet or elementary sounds, which must be first learned, and which reason may then combine in countless ways into words and sentences, but does not alter in form or number.

The argument particularly addressed to Pflüger and those who agreed with him starts from the general assumption that the motor states of the soul, transformed in the brain alone into physical changes of matter, are propagated in this new form through the centrifugal nerves to cause contractions of the muscles. And conversely, physical changes set up in the peripheral ends of sensory nerves are conducted unaltered in character to the brain, where occur all those processes by which physical excitation is transformed into the psychic form of sensation, a feeling.[1] After repeating Pflügers experiments with the decapitated frog, which, when one foot was amputated, used the other to remove the acid, and the eel's tail which reacted from, instead of into, the flame, Lotze calls these movements not only teleological, but at the same time adapted to the special circumstances of the stimulus. And he pronounces them not due to intelligence or sensation present in the cord, but to the *after effects* of these. Acts of the conscious will, he says, leave behind "not only unconscious recollections, but also physical impressions in the organs of the central nervous system," and these latter, as well as the soul itself are sufficient to account for Pflüger's phenomena. States which can be first caused only by consciousness may actively persist as conditions of a substance after consciousness has vanished. By practice and training a secondary character, which survives decapitation, is thus imparted to subordinate centres, ennobling the already complex apparatus by the possession of new associations between sensation and motion.[2] Pflüger, he continues, might have argued a limitless series of

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[1] Lotze. Göttingen gelehrte Anzeiger. 1853, III, p. 1737 ff.

[2] This notion of Lotze's has received corroboration in the experiments of Steiner, reviewed in the last number of this JOURNAL, Vol. III, No. 2, (1890.), p. 187, middle of the page.

souls for all, even the smallest, function and part of the body; each soul stimulated to greater, though we know not what, activity by severing it from its superior centre. All this we must reject as incompatible with the unity of the individual soul. In the light of this conception Lotze attempted to explain in detail Plüger's Laws of the phenomena and found his crucial experiments too uncertain to sanction the inferences drawn from them.

But once more the argument swings to the other extreme, and this time with the weight of Auerbach's[1] authority. Auerbach repeated Pflüger's experiments, he tells us, on more than three hundred frogs and many eels, pikes, tritons, snakes, lizards and rabbits, and reaches the conclusion that psychic force may be set free in any part of the brain or spinal cord. Hence the integrity of consciousness suffers, if the central nervous system is injured. It is difficult to see, however, wherein Auerbach carried the argument beyond the point at which Pflüger left it. He nowhere even reaches the level of Lotze's view.

With Lotze we do advance in thought a step beyond the comparatively crude, simple, mechanism of Marshall Hall to a mechanism of the utmost delicacy, a mechanism susceptible of the nicest adjustments, capable of education, and of prolonged, independent and complex activity. And why is it, queries Lotze,[2] that the whole world bristles up the moment the fact of mechanism in psychology is mentioned? Men seem to think that the soul loses something of its dignity and that the highest moral interests are endangered, if we do not attach to the smallest details of life the full operation of free will. "This is the dogma of the schools." On the other hand how much of our education is directed to the very end of making the daily round of life mechanical? Habit, as people term it, is only another name for mechanism.

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[1] Auerbach. Günsburg's Zeitschrift für klin. Med. 1855. pp. 452—96.
[2] Wagner's Handwörterbuch, Lotze, op. cit. p. 200.